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Model-based Insights into Individual Differences in Performance

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Abstract

Our recent work on the modeling human-like multi-task behaviors has led to unexpected insights into a possible mechanism contributing to individual differences in human performance. We begin by outlining our modeled conflict resolution strategy for the graceful sharing of perceptual, cognitive, and motor resources among multiple in-process tasks. We then discuss how that same mechanism might drive individual differences in concurrent task execution. The modeled strategy, in this case operating on subtask structure, may be one contributor to how individual operators differentially decompose and interleave concurrent tasks. We further suggest that the same mechanisms and structures might evolve over time as an operator learns to concurrently engage multiple related tasks. Theory building for multi-task behaviors as explored through model development has opened a new line of inquiry into potential mechanisms for individual differences in performance.

Summary

In grounding human performance modeling in a theory instantiated in an architecture we have sought to not only produce human-like behaviors in a model but also provide insight into the assembly and functioning of the individual capabilities that come together to produce these behaviors. Much of the research effort has been directed at understanding and reproducing expert behaviors at workplaces that demand concurrent execution of multiple tasks. What we have found surprising is that the mechanisms that we have in place to address resource contention in multitasking have provided the basis for new insights into the mechanisms that we now suggest may be important contributors to individual differences in performance.

We begin with an introduction to the architecture and implementation framework for our models. The discussion is restricted to the essential elements of the architecture that support the modeling of multi-task performance. We then provide a brief overview of the unmanned aerial vehicle (UAV) environment with a focus on the role of the sensor operator (SO). With the necessary background in place, the mechanisms within the model that lead to individual differences in performance are examined. The final section briefly outlines possible future directions for the research effort.

Modeling Human Performance in D-OMAR

To understand how it was possible to gain insight into possible mechanisms leading to individual differences in performance we will start by providing an overview of the basic elements of the models we have been building and the theory and architecture that underlies the models. We will look most closely at how the architecture supports the human-like multi-task behaviors of the models.

The models have been used to represent small teams such as commercial aircrews, air traffic controllers, or UAV operators. Each modeled team member is typically seated at a complex workplace executing procedures that require coordination with other team members. From a bottom-up perspective, the models are dependent on suite of perceptual and motor capabilities. Perceptual capabilities focus on vision and audition with limited processing of haptic input. Motor requirements focus on hand and eye operations.

From a top-down perspective, we are concerned with supporting task completion in the models. Model behaviors are defined by goals and procedures in which the goals define the objectives being undertaken by the models. A goal includes a plan with sub-goals that decompose the top-level goal as necessary. The actions taken by the model are expressed as procedures invoked by the sub-goals within a plan. The procedures typically have numerous branch points to address contingencies that may be encountered. As defined by this framework, the objective of a *task* are expressed as a goal with a plan made up of sub-goals—the execution of the task is conducted by the sub-goals' procedures. Goals and procedures are elements of the Simulation Core (SCORE) language used to define model behaviors.

Our concern has been to model expert performance in which many of the operator's skills have been highly automatized. Workplace situations require the concurrent processing of multiple tasks and much of our research has been concerned with how human error intrudes in highly skilled behaviors.

We will look at the mechanisms in the models that are thought to support multiple task behaviors in humans. We will suggest that the same mechanisms may be at work in producing individual differences in performance.

In modeling the concurrent demands of multiple tasks it is necessary to impose human-like bounds on model performance. Perceptual and motor capabilities, hands and eyes, are resources that in most circumstances can only serve one task at a time. The concurrent demands of two tasks each requiring a coordinated hand-eye operation requires a conflict resolution strategy. We base the access to the functional elements, hands and eyes, on the priorities of the contending parent tasks. A proactive action to set a new UAV altitude will preempt a background instrument scanning tasks. The background scanning task will simply resume once the altitude has been set. If we think of the goals and procedures of a task as forming a tree, the contention is seen to be resolved at the leaf nodes of the tree.

Exactly the same conflict resolution protocol also addresses high-level protocol issues. On a commercial flight deck, the aircrew will interrupt their conversation to listen to a communication from the air traffic controller. The tasks associated with attending to the air traffic controller are established with a higher priority, and hence, will interrupt the lower priority intra-crew conversation.

In each case, a new procedure encounters a running procedure with which it conflicts. If the new procedure has higher priority, it will continue execution and the running procedure will be suspended. Otherwise, the new procedure will be suspended and the running procedure will continue to completion. Notably absent is the requirement for an explicit executive reasoning over procedures to produce expert multi-task behaviors.

We will suggest that the same conflict resolution strategy that addresses resource contention and high-level protocols in multi-task behaviors may also play a role in individual differences in performance.

The UAV Domain

Unmanned aerial vehicle (UAV) operations provided the domain for the modeling research. The UAV team for a mission included an aerial vehicle operator (AVO), a sensor operator (SO), and a multi-function operator (MFO) that may be supporting one or more UAV teams. Our focus was on the SO as he or she conducted surveillance of at a commercial airport where armed agents were loading and fueling a commercial aircraft in preparation for departure. The SO conducted the observations using a TV camera and an infra-red (IR) sensor.

The tasking for the mission was governed by a text document containing the Essential Elements of Information (EEI) that defined mission objectives and provided information for EEI processing. In the scenario as developed, there were six EEIs: (1) identify the target aircraft among the aircraft at the airport; (2) count the armed agents; (3) monitor the fueling of the aircraft; (4) monitor the loading or unloading of the aircraft; (5) check the target aircraft's engines for start-up; and finally (6) conduct surveillance. The SO interpreted the requirements of the EEIs and conducted the necessary sensor operations. Each of the EEIs was accomplished using the TV sensor except the checking of the target aircraft's engines for start-up that required the use of the IR sensor. As the SO processed the EEIs, the SO communicated his or her findings to the MFO and AVO.

Multi-tasking by the Sensor Operator

We can begin to think about the SO's execution of the EEIs by looking at the characteristics of the individual EEIs that impacted their execution. The individual EEIs range from notably simple (e.g., count the armed soldiers) to potential quite complex—the surveillance of the airport could play out in any number of ways. Some of the EEIs were completed immediately (e.g., counting of the armed agents), while most of the EEIs involved the monitoring of events that had an indeterminate timeframe. Lastly, there were dependencies among the EEIs. The target aircraft had to be identified before any of the other EEIs could be pursued; events detected in executing one EEI could impact the pursuit of another EEI.

There is a nice alignment between what we will speak of as a *task* and the operations demanded of the SO as he or she worked through an individual EEI—each a well-defined, notably compact unit of work, allowing that some are not immediately completed. (The exception is the surveillance EEI that has been decomposed into several concurrent tasks in the model.) Hence, in terms of the SO's work, the processing of an EEI constitutes a task guided by the goal of completing the objective defined by the EEI.

The tasks of an EEI then include the reading of the textual material defining each task, mapping the task defined by the EEI to the operations to be performed, and the execution of the required operations. Given that a UAV mission will typically include multiple EEIs, we can now broadly define bounding approaches to accomplishing the necessary work. A first approach, what we will term the read-process approach, can be defined as read-process in the sense that each EEI is read and executed in turn. At the other extreme is the read-read approach, where an SO might read all the EEIs up front and then process them with much concurrency.

In general, the read-process approach will break down simply because the SO will encounter EEIs that can not be quickly resolved and hence, would prevent starting the processing of subsequent EEIs. It is necessary to read ahead and this of course leads to the concurrent execution of multiple tasks. Self evident in its shortcomings, the read-process was not explored using the model. At the other extreme, the read-read approach was explored in the modeling, followed by an examination of the trace of the behaviors produced that showed anomalies in task execution. The exploration of the aspects of the model that drove the middle ground in behaviors between read-read and read-process is discussed in the next section.

Insights into Individual Differences in Performance

The read-process approach to EEI processing would readily have been established using conflicts between the reading of an EEI and the procedures for completely processing each EEI. An EEI would be read and the processing initiated. The established conflict would prevent the reading of the next EEI until processing of the first EEI was completed. It would have been a dense conflict structure leading to highly constrained and unsatisfactory behaviors.

What this initial finding suggests is that the structure of the procedure hierarchy with respect to conflicts between procedures drives the fine structure of task processing in important ways. Changes in the conflict structure for procedures leads to changing patterns of task execution. A richer structure for conflicts yields a more rigid and more orderly execution of a task by inhibiting interruptions. What this counter intuitively suggests is that simpler conflict structures enable more complex fine-grained interleaving of competing tasks—the broad range of variation is suggestive of what might drive individual differences.

The populating of the conflict structure previously focused on regions closer to the roots of the goal-procedure trees to establish protocols and closer to the leaves to govern access to resources. What is interesting is that our attention has been drawn to the, until now, neglected middle ground of the procedure trees. We modeled a sparse conflict structure, however, examination of the traces of the trials with this relaxed structure uncovered some questionable model behaviors. A model would read a latitude (for pointing the sensor package) from an EEI, dial in the latitude at the console and then jump off to an unconnected step in the processing of another EEI, maybe even reading a new EEI, before returning to set up the longitude associated with the sensor pointing operation. The behaviors were not wrong; they were just not the likely behaviors of a good operator.

As we pursued the process of examining the middle levels of the conflict structure and adding, removing, or adjusting the pattern of conflicts, we uncovered a broad range through which procedures for multiple tasks could be interleaved. What is new is the conflict structure's potential role in establishing individual differences in task execution. The findings suggest the particular structure of the conflicts as a driver of these individual differences. Moreover, there is the suggestion that changes in the conflict structure over time might be one aspect of an individual's progress in learning to more readily and robustly achieve the successful completion of multiple ongoing tasks. We might start the learning of a new set of tasks with a complex, dense conflict structure and through relaxation of the structure—the selective removal of conflicts—learn a more sophisticated processing of multiple ongoing tasks.

Next Steps

Lastly, we will outline future directions for examining model-based insights into individual differences in performance.